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RESEARCH AND TECHNOLOGY ADVISORY COMMITTEE ON MATERIALS AND STRUCTURES

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REPORT OF MEETING

OCTOBER 13 and 14, 1971

NASA

RESEARCH AND TECHNOLOGY
ADVISORY COMMITTEE
ON
MATERIALS AND STRUCTURES

REPORT OF MEETING

OCTOBER 13 and 14, 1971

OFFICE OF ADVANCED RESEARCH AND TECHNOLOGY

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

SUMMARY

The third meeting of the NASA Research and Technology Advisory Committee on Materials and Structures was held on October 13 and 14, 1971 at NASA Headquarters.

The Committee recommended:

That NASA endorse the operation of DOD Information Centers and if necessary, provide a portion of support.

The Committee acted to:

1. Request a NASA response to the recommendations of the Ad Hoc Panel on Fracture Control prior to final Committee action on the recommendations.

2. Request a NASA response to the recommendations of the Ad Hoc Panel on Composite Materials Applications including initiation of a cost-benefit study on STOL aircraft systems, and preparation of a 5-year plan for R&D. Endorsement of the Panel report was withheld pending this action by NASA.

3. Request position and status report from NASA on nondestructive evaluation research and manufacturing technology.

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A	Report on Priorities in Engine Materials Panel Recommendations
B	Report of Ad Hoc Panel on Evaluation of Aircraft Structures Subcommittee Recommendations
C	Report of Ad Hoc Panel on Fracture Control
D	Report of Ad Hoc Panel on Composite Materials Applications

REFERENCES

(a) Report of the NASA Ad Hoc Committee on Failure of High Strength Structural Materials, August 1971

(b) NASA Report TMX-2378 "NASTRAN: Users' Experiences", September 1971

NASA RESEARCH AND TECHNOLOGY ADVISORY COMMITTEE ON MATERIALS AND STRUCTURES

Chairman - Mr. Ira G. Hedrick
Grumman Aerospace Corporation

Vice Chairman - Mr. William T. Shuler
Lockheed-Georgia Company

Members

Dr. Robert I. Jaffee
Battelle Memorial Institute

Mr. Louis P. Jahnke
General Electric Company

Dr. Alan M. Lovelace
Air Force Materials Laboratory

Dr. Richard H. MacNeal
MacNeal-Schwendler Corp.

Mr. Edwin M. Ryan
Naval Air Systems Command

Mr. Howard Siegel
McDonnell-Douglas Corp.

Mr. M. Jonathan Turner
The Boeing Company

NASA Members

Mr. G. Mervin Ault
NASA Lewis Research Center

Dr. George W. Brooks
NASA Langley Research Center

Executive Secretary - Mr. George C. Deutsch
NASA Headquarters, OART

Recording Secretary - Mr. Norman J. Mayer
NASA Headquarters, OART

Guests

Dr. James W. Mar
Headquarters, U.S. Air Force

Mr. E. Dwight Bouchard
McDonnell-Douglas Corporation

Mr. Richard R. Heldenfels
NASA Langley Research Center

Mr. Charles E. Cataldo
NASA Marshall Space Flt. Ctr.

INTRODUCTION AND ROLL CALL

The third meeting of the NASA Research and Technology Advisory Committee on Materials and Structures was convened at 8:30 AM on October 13, 1971 at NASA Headquarters. The Chairman welcomed the members and guests and requested approval of the minutes for the May 5 and 6, 1971 meeting. There were no additions or corrections and the minutes were approved. All members were in attendance except Messers Turner, Jahnke, and Ryan. Mr. Ryan attended on the second day.

CHAIRMAN'S REPORT

OART Program Plan

Mr. Hedrick reviewed the comments submitted by the members concerning the presentation of the OART Program Plan for Aeronautics and Space made during the previous (special) September 21-23 meeting. The comments were summarized in a letter to the Research and Technology Advisory Council (RTAC) in response to Mr. Jackson's request. The letter was also included in the minutes of the special meeting. Although there were many opinions on various items of the presentation, there was a consensus on the need for more NASA effort on materials and structures, for less emphasis on hardware development in aeronautics, and more effort on aeronautical structures research, but not necessarily at the expense of space research in this area. The Committee voted for a revision in the Chairman's letter to RTAC which would indicate a consensus in favor of increased effort in fracture and fatigue research, but not a diminished effort in composites. A revision to the letter will be issued by the Chairman.

Mr. Hedrick stated that he was Chairman of a Panel of RTAC which would report on the responses of the various Committees to the OART program presentation. He also promised to review this information at the next meeting of the Materials and Structures Committee.

Committee Operations

Mr. Hedrick summarized the responses of Committee members to his request for comment on important topics and on Committee operations which he made following the initial meeting of the Committee. He noted that several of the topics suggested were on the agenda and that others would be considered in the future. These included automated procedures for aircraft design; structural/materials interaction, selection, and integrity; incorporation of materials and design concepts for minimizing environmental problems; and high temperature structures and materials.

Some members commented that Committee work was requiring too much time and suggested other methods of operation to alleviate the problem.

Joint Committee Panel

The Chairman noted that Dr. Lovelace and Dr. Jaffee were serving on an Ad Hoc Panel to the Research Committee for an evaluation of the NASA basic materials program.

SECRETARY'S REPORT

Ad Hoc Panel Operation

Mr. Deutsch reviewed the status of ad hoc panel formation and operation. It is presently planned to contract with the National Materials Advisory Board (NMAB) for the operation of panels. This would provide greater flexibility in terms of choices of members and Committee workload. Some members suggested alternative action ranging from other types of contracted operation to preparation of ad hoc reports entirely by NASA staffs. The NASA members felt that reports prepared by NASA would create an unnecessary burden on limited personnel and would not provide the external advisory inputs required. Most of the Committee felt that ad hoc panels were capable of performing broad studies and making general recommendations, whereas in-depth programs had to be formulated on the basis of studies either by NASA staffs or by contractors. There is obviously a need for studies which contain quantified recommendations and specifically defined programs. However, these studies are expensive to produce, require more time, and are usually beyond the normal capabilities of panels and committees.

Some members suggested that even where NASA has no capability or has not performed in a particular area, there were still benefits to be derived from investigating a problem as an issue. The Committee concluded the discussion by suggesting that both NASA and Committee (NMAB Panel) studies be tried on a couple of critical issues in order to evaluate the efficacy of each method.

Information Centers

In response to the Committee's request, Mr. Deutsch reviewed the status of NASA use and support of various government sponsored information centers. He pointed out that OART selectively supports some centers, but does not provide general support to all centers. At present, DOD has imposed a user charge for the DOD Information Analysis Centers to cover one-half of their cost. DOD has requested NASA to provide 25% of the support for all centers. Although there are no plans to provide general support, an OART position on the subject has not been established.

Prior to the meeting, Mr. Hedrick distributed a Grumman appraisal of DOD Information Analysis Centers which described their function, charge policies, and their value to Grumman.

On the basis of the above information, Mr. Ault was requested to express a Committee position on the subject which was approved by the Committee as follows:

> "The Committee expresses a consensus view that the information centers relating to the materials and structures field fulfill a much needed function and that NASA and its contractors benefit greatly from the services provided.
>
> The Committee indicates that the high quality of the better centers is the result of the association of the information collection and retrieval function with a highly qualified technical staff in the subject area. The staff evaluates, screens, and collates the data and provides expert technical interpretation and consultant services.
>
> The Committee expresses the view that the DOD plan to attempt to provide 50% support of the centers by a service charge is almost certain to fail. Further, the Committee states that the income derived by this approach should not be used to measure the value of these centers. The time and cost of processing purchase orders for the services will be a severe deterent to their use and in fact will inhibit the necessary free flow of information. (Undoubtedly, the government will still be paying whatever support is provided by this financing method, but at two or three times the cost because of additional overhead.)
>
> In response to these expressed views the Committee recommends that:

1. A vigorous effort be made to keep these Centers viable. If necessary, NASA should provide a portion of the support of these Centers. However, it may be desirable for the NASA staff to determine which of these centers are of greatest value to NASA and its contractors and then to distribute the support in proportion to this evaluation.

2. Because the centers are of service to the entire cross section of NASA's activities, it is further suggested that the necessary funding be provided from funds normally allocated to all Offices of the agency."

Technical Information Documents

All RTAC Committee members have been given the privilege of receiving various NASA published scientific and technical information documents. Forms were distributed to the Materials and Structures Committee members for selection of distribution categories.

AD HOC PANEL REPORTS

Engine Materials Evaluation Panel

The Panel was established during the May 5 and 6 Committee meeting to evaluate recommendations made by the Engine Materials Subpanel of the predecessor Materials Advisory Subcommittee. Dr. Jaffee, Chairman of the Panel, sent a questionnaire to the Panel members, requesting that they classify the recommendations in three categories: Urgent, Extremely Desirable, and Desirable. A summary of the Panel report was presented by Dr. Jaffee. He noted that the strongest recommendations were concerned with establishment of a highly competent Nondestructive Evaluation (NDE) group within NASA, and for NASA encouragement of more cooperative action within the titanium industry for establishment of standards. Other "Urgent or Extremely Desirable" categories included reliability of engine components as established by NDE measurements and correlation with life prediction. During discussion, the Committee generally agreed that all items on the list are important and none should be dropped. Items that produce penalties to manufacturers in terms of increased costs or other, such as NDE, needed Government support and development.

It was also agreed that NASA should encourage industry to set up standards for materials such as titanium and other metals when applied to critical components whose performance influences aerospace vehicle safety.

The Committee accepted the Panel report with appreciation and voted to include the report in the minutes of the meeting. This action terminated the Panel. The Panel report and questionnaire are included in Appendix A.

Aeronautical Subcommittee Evaluation Panel

The Panel was established during the May 5-6 Committee meeting to evaluate the recommendations of the predecessor Aircraft Structures Advisory Subcommittee for V/STOL, transonic and hypersonic aircraft. Comments on these recommendations were requested from the NASA Research Centers and from members of the Committee and the previous Subcommittee. On the basis of these responses, a meeting was held on September 20, 1971 to evaluate the comments and formulate a report. This report was distributed to the Committee members prior to the meeting and is contained in Appendix B.

Mr. Shuler, a member of the Panel, presented an oral review of the report. The Panel generally concurred that the previous Subcommittee recommendations continued to represent important problem areas for NASA research. Several special emphasis items were added to the list. An in-depth assessment of NASA Center activity in relation to the listed recommendations was not made, nor were priorities established for these items. It was recognized that in many cases efforts were underway within NASA.

Some committee members expressed a need for listing items in order of priority, even though this was difficult to do on the broad scale covered by the Panel investigation. The prioritizing of items would help to establish the major targets for both National and NASA concentration. The Committee accepted the Panel report with thanks and requested that NASA Centers continue to respond to this list of recommendations during future meetings. This action terminated the Panel.

Ad Hoc Panel on Fracture Control

The Panel was established prior to the first meeting of the Committee. The members of the Panel are listed with the final report in Appendix C. Two meetings of the Panel were held prior to preparation of a final report to the Committee.

The final report was distributed to all members during the meeting. Mr. Heldenfels of the Langley Research Center provided an oral review of the report in place of Mr. Jahnke, Chairman of the Panel. The Panel reviewed the status of research on three fundamental elements leading to fracture: initial flaw size, subcritical flaw growth, and critical flaw size. The interaction of these elements with loads and environments and analytical procedures to account for such effects were also discussed. The complexities of applying fracture theory to design were reviewed by the Panel. In addition, the Panel considered vehicle operational aspects and the continuing need for parametric studies.

The Panel's conclusions and recommendations centered upon the need for increased NASA in-house and contracted research on a continuous basis for several years. Emphasis was placed on parametric studies, development of approaches for standardized test methods, generation, collection, and dissemination of data, a highly concentrated effort on NDE research, metallurgical development, improved analytical methods, and interaction studies.

As an example of current practice in the application of fracture control methods to actual design and construction, Mr. Siegel introduced Mr. E. Dwight Bouchard from the McDonnell-Douglas organization, who made a presentation on the F-15 Fracture Control Program. His review included the elements of the program which were as follows:

1. Test program requirements
2. Test data on micro-subsurface flaws
3. Specimen types
4. Surface flaw growth data
5. Fatigue critical factors in titanium
6. Analysis and estimation of flaw growth under spectrum loads
7. Data on test results vs. predicted flaw growth
8. QC requirements on major structural components
9. Test results on fracture toughness vs. yield strength
10. Evaluation of NDE capability
11. Fracture mechanics guidelines

Mr. Bouchard suggested that research and development was needed in NDE, fracture control methods which are system oriented, and derivation of constant amplitude data from specimen tests.

Mr. Siegel observed that it was essential that NDE specialists be involved in development programs from their inception, including the design phase, if fracture control is to be effectively incorporated in design.

Mr. Heldenfels also presented the Langley program in Fatigue and Fracture Research. He showed this to be a continuing program which is revised as new problems and new information become available. This program includes the following items:

1. Parametric design study

2. Design criteria

3. NDE

4. Fatigue and fracture technology developments

5. Automated design

A comparison of NASA effort in NDE with DOD and Industry was shown. The distribution of effort among the major methods was also shown.

The facets of NDE research planning using holography, radiography, ultrasonics, and acoustic emission, and others were also listed in comparison to the problem areas of composites bonding, crack growth, flaws, welding integrity, and honeycomb panels.

Examples were given of NDE support for flight projects. Various fatigue data from test specimens on metals and composite reinforced metals were shown. The relationship between crack growth and fatigue was given in several examples. A three dimensional plot of initial crack length, number of cycles, and specific strength with typical curve shapes for D6AC, 6-4Ti, and 2024 Al was shown as an example of an approach to least-weight material selection for specified life and initial crack length. A 10-year plan was described which has been established to generate support analysis and data to place fatigue design on a NASTRAN-like basis by 1989.

Mr. Heldenfels also distributed copies of a preliminary criteria document "For the Fracture Control of Space Shuttle Structures" dated June 1971.

In the discussion of the report, the Committee noted that the study made by NASA on failure of high strength materials, reported in Ref. (a), and a counterpart study by the Air Force contain data and discussion of failures attributed to various fracture or fatigue mechanisms. Copies of the NASA report were distributed to the Committee prior to the meeting. The Air Force report has not been issued.

Objection was made to the figures presented in the Introduction portion of the report on the cost of past structural failures. It was felt that these could not be wholly supported and also tended to lead to erroneous conclusions concerning actual cost savings. The Committee agreed to accept the Panel's report with revised wording with respect to past failure cost data. The Committee expressed thanks to the Panel and approved the following action:

1. NASA was requested to provide a response to the report in terms of:

    a. Research in progress

    b. Identification of barriers to particular recommendations

    c. Plans for expansion

    d. Resource figures

2. The Committee will finalize their recommendations concerning the Panel report following review of the NASA response.

3. The Ad Hoc Panel was terminated.

<u>Ad Hoc Panel on Composite Materials Applications</u>

The Ad Hoc Panel was established prior to the first meeting of the Committee. The Panel members and the final report are contained in Appendix D. Two meetings of the Panel were held with the results of the first meeting being reported during the May 5 and 6 meeting of the Committee. The Committee responded by requesting further action by the Panel with regard to evaluating present NASA, DOD, and Civil effort and recommending a future NASA program.

The last meeting of the Panel was held on July 13, 1971. Following this meeting, a final report to the Committee was prepared. In order to respond to the Committee's requests, changes were made to the Panel membership to include NASA and other DOD representatives. Mr. Shuler, Chairman of the Panel, presented a summary of the Panel report. He introduced the subject by including data from various Lockheed advanced systems studies which showed the high potential for structural improvements in aircraft resulting from the incorporation of composites.

The Panel report stated that whereas there appeared to be adequate emphasis on military aircraft applications, little research and development was directed toward civil aircraft or engine application. The specific work areas that NASA should pursue would be defined from system studies currently underway and from other cost benefit studies. A primary broad role for NASA was the development of technology to provide the confidence required for acceptance of composites by industry in a manner similar to previous NACA work on aluminum structures. Improved coordination with DOD and FAA was emphasized with the objective of technology utilization among the various programs. It was concluded that present funding levels would not permit a viable or significant program and that large increases were necessary. The Panel report concluded with a set of proposed recommendations for Committee action.

In the discussion of the report, some Committee members addressed the question of the cost of advanced composites and stated a need for utilization of larger quantities to reduce costs. This could be partly accomplished by incorporation in secondary as well as primary structures. The reduction in cost of aircraft fabrication was recognized as a greater need and one in which advanced research and technology might produce a higher payoff. The Committee recognized the need for reliable fundamental design data as a major step toward establishing confidence.

Dr. Lovelace emphasized the need for definition of a specific program for composite materials application development. He stated that similar program definition was in the planning stage within the Air Force and suggested formation of an Air Force/NASA group for mutual planning.

Dr. Brooks distributed copies of a proposed Langley plan for cost-benefits studies in the application of composites to aircraft structures. Committee comment on the plan included the suggestion that the effort be confined to STOL applications in view of current studies on advanced transport types. It was also suggested that the study start with present material costs, but include projections of cost reductions and establish goals for same. It is not planned to include propulsion applications in the study due to resource limitations, even though such studies would be of benefit if performed concurrently with STOL studies.

Mr. Hedrick requested Dr. Lovelace to prepare a recommendation for Committee action which was approved as follows:

> The Committee accepts the report (July 13, 1971) of the Ad Hoc Panel on Composite Materials Applications to Aeronautical Systems and hereby discharges the Ad Hoc Committee with thanks for a good job.
>
> The Committee does not, at this time, endorse the recommendations contained in the above report pending the completion by NASA of the following actions:
>
> 1. Completion of the ATT cost benefit studies on materials design optimization.
>
> 2. Initiation of a cost performance benefit study relating to the relative utilization of composite materials and structures in a STOL Transport (airframe and propulsion).
>
> 3. Commissioning the in-house preparation of a NASA 5-year R&D plan addressing in detail goals, defining cost, program content, scope and timing, as well as interrelationships with existing industry and DOD programs.

NEW ISSUES AND PROBLEM AREAS

General

Two topics were selected prior to the meeting for Committee discussion and consideration for further study by ad hoc panels. These were NDE and Manufacturing Technology. The Chairman furnished the members with two broad critiques prepared by his staff for each subject to establish a basis for discussion.

Nondestructive Evaluation Research

Mr. Ault reported that approximately 2.5 man-years directly and 5 man-years indirectly were devoted to NDE at Lewis, with approximately $250,000 of contract effort. Plans call for an expansion of this effort in future years. In addition, a complimentary effort was being pursued as part of the Safety Institute at Lewis. The issuance of a monograph on NDE is being considered.

Mr. Cataldo stated that approximately 15 people were engaged in NDE research at Marshall.

Mr. Siegel mentioned that the application of NDE is difficult and probably will always be so. There was a need for development of better acceptance criteria in specific cases in order to produce greater effectivity from the methods employed.

Dr. Lovelace noted that techniques now available were not necessarily being applied. There is a relationship between criteria and life prediction.

The Committee voted to request position and status reports on NDE primarily from the Lewis and Marshall Centers.

Manufacturing Technology

Dr. Brooks noted that approximately 8 people are now involved at Langley in a manufacturing technology study program. This effort will include materials and system engineering, fabrication, visits to aerospace industries to determine high priority problems NASA should address, derivation of long term application data in composites, and use of ground vehicles such as experimental tractor trailer assemblies to develop load spectra and long time endurance data.

Mr. Ault reported manufacturing technology work at Lewis in connection with fabrication and joining of materials, for example, filament wound tank construction and T-D Nickel fabrication, although this effort has not been singled out as a discipline.

It was noted during the discussion that in most cases designs are not evolved for manufacturing efficiency. A possibility exists for computer aided design and integration with manufacturing technology. Large cost savings are indicated by elimination of drawings and hand work.

Dr. Brooks will report to the Committee at a future meeting on the results of a Langley/Industry survey of technology needs, and on aspects where NASA can contribute.

REVIEW OF CENTER AND MEMBER REPORTS

Members' reports were received from Messrs Hedrick, Shuler, Lovelace, Ryan, Siegel, and Turner. Center reports were submitted by Langley, Lewis, and Ames Centers.

Dr. Brooks presented a review of the elements of the NASTRAN program. He noted that NASTRAN is the largest, most comprehensive, nonproprietary, general purpose, finite element computer system in existence today. It is administered by the NASTRAN Systems Management Office (NSMO) at the Langley Research Center. The first public release of the program was made in November, 1970. The NSMO covers a range of activities on the program including centralized program development, coordinating user experiences, system maintenance, development and addition of new capability, and focussed R&D.

A Users' Colloquium was held at Langley on September 13-15, 1971. This included a presentation of 52 papers from Industry, Government, and Universities on application experience on statics analysis, vibration, dynamics, structural design, systems and operational problems, evaluations and innovations, and new capabilities. These papers are contained in NASA Report. (Ref. (b))

Dr. Lovelace described the Air Force Materials Laboratory effort on Application and Technology Area Forecasts and promised to distribute copies of these forecasts and abstracts of the 1970 Air Force Materials Laboratory reports to the Committee members.

Mr. Ryan reported that he is a member of an NMAB ad hoc committee on "Application of Fracture Prevention Principles to Aircraft". The committee consists of two panels on Materials and Design Utilization. Its objective is to assess the status and significance for advanced aircraft design using the latest concepts of fracture prevention and to define a program for the Air Force which would allow such application. The committee is scheduled to complete their assignment by the end of CY 1971.

PLANS FOR NEXT MEETING

The next meeting was planned for March 15 and 16, 1972. The site of the meeting will be decided at a later time. The agenda will include the following:

1. NASA reports on fracture control program
2. NASA composite materials research program plan
3. NASA position and status reports on NDE
4. Dynamics and aeroelasticity problem areas
5. Status report on basic materials research panel
6. Titanium industry status report

The meeting was adjourned at 3:00 PM on October 14, 1971.

Respectfully submitted,

Norman J. Mayer
Recording Secretary

APPENDIX A

AD HOC
PANEL
REPORT

NASA RESEARCH AND TECHNOLOGY ADVISORY COMMITTEE ON MATERIALS AND STRUCTURES

PRIORITIES IN ENGINE MATERIALS RECOMMENDATIONS

REPORT OF AD HOC EVALUATION PANEL

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OCTOBER 1971

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NASA RESEARCH AND TECHNOLOGY ADVISORY COMMITTEE
ON MATERIALS AND STRUCTURES

PRIORITIES IN ENGINE MATERIALS PANEL RECOMMENDATIONS

Introduction

At the Materials and Structures Committee Meeting, May 5-6, 1971, it was requested that priorities be established for the Engine Materials Subpanel Recommendations, given in the Minutes, Appendices A-1 and A-2. A questionnaire was sent to the Engine Materials Panel requesting that they classify the recommendations in three categories: (1) urgent, (2) extremely desirable, and (3) desirable. Of the 20 questionnaires circulated, 16 responses were received. The recommendations were then ordered in priority by multiplying all "urgent" replies by the factor 1, "extremely desirable" replies by factor 2, and "desirable" replies by factor 3, and dividing by the number of replies. Thus a perfect "urgent" score would have a rating of "1".

Priorities

The results of the polling are shown in Table 1.

Discussion

The top-ranked recommendations of the Engine Materials Panel all are concerned with reliability of engine components as established by NDE measurements, their correlation with part-life, and application to life prediction. The remainder of the Engine Materials Panel recommendations are concerned with more-or-less straightforward research and development of improved engine materials, which is of course the sort of thing normally supported by the OART Centers. The recommendation that NASA encourage the titanium industry to set up cooperative actions received a vote of "extremely desirable".

In addition to the above specific recommendations, The Engine Materials Panel made its strongest recommendation to the new Materials and Structures Committee that a highly competent NDE group be established at one of the NASA Centers.

Submitted by R. I. Jaffee

RIJ:jj
10/12/71

TABLE 1. SUBPANEL RECOMMENDATIONS

Ranking - (1) "Urgent" to (2) "Extremely Desirable"

1.	<u>Subpanel on Nondestructive Evaluation</u>	
	3. Correlations between NDE measurements and part-life, in actual or simulated service	1.6
2.	<u>Subpanel on Superalloys</u>	
	4. Life prediction	1.7
3.	<u>Subpanel on Titanium</u>	
	3. Life prediction	1.8

Ranking - (2) "Extremely Desirable" to (3) "Desirable"

4.	<u>Subpanel on Superalloys</u>	
	1. Trace elements	2.0
5.	<u>Subpanel on Nondestructive Evaluation</u>	
	2. Development, application, and automation of new NDE techniques and tools, with attention to real factory and overhaul situations	2.0
6.	<u>Subpanel on Superalloys</u>	
	3. Future developments (powder metallurgy, dispersion strengthening, directional solidification and thermomechanical processing)	2.1
7.	<u>Subpanel on Hot-Corrosion</u>	
	1. Hot corrosion coatings	2.2
8.	<u>Subpanel on Titanium</u>	
	2. Standardization action	2.2
9.	<u>Subpanel on Superalloys</u>	
	2. Stability and ductility	2.2

TABLE 1. (Continued)

Ranking - (2) "Extremely Desirable" to (3) "Desirable"

10.	Subpanel on Titanium	
	6. Alloy and process development with high fracture toughness for ambient and intermediate temperature	2.3
11.	Subpanel on Composites	
	1. Characterization and processing	2.4
12.	Subpanel on Nondestructive Evaluation	
	4. Collecting and disseminating NDE information throughout aerospace industry, including instruction of material and design engineers in the use and power of NDE technology	2.4
13.	Subpanel on Titanium	
	4. Development of protective coatings	2.5
14.	Subpanel on Nondestructive Evaluation	
	1. Fundamental studies of phenomena potentially useful for NDE	2.5
15.	Subpanel on Titanium	
	1. Titanium fires	2.6
16.	Subpanel on Titanium	
	5. Powder metallurgy	2.7

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Telephone (614) 299-3151
Telex 24-5454

August 5, 1971

To Members of the NASA Research and Technology
Advisory Panel on Materials For Aircraft Engines

Gentlemen:

The newly formed NASA Research and Technology Advisory Committee on Materials and Structures is considering what to do about the recommendations made by the subpanels of the Engine Materials Subpanel, now disbanded. To facilitate this consideration, I would appreciate your checking the attached listing of recommendations developed at the April 7, 8 meeting for NASA action in the following order of priorities -- (1) urgent, (2) extremely desirable, or (3) desirable. A copy of the recommendations made at the April 7, 8 meeting is appended.

Let me have this back by September 1 in order to prepare a report on engine material priorities to the M. & S. Committee for its September 21-22 meeting.

Yours very sincerely,

Robert I. Jaffee

RIJ:jj

Attachment

Airmail

SUBPANEL RECOMMENDATIONS

	(1) Urgent	(2) Extremely Desirable	(3) Desirable
Subpanel on Superalloys			
1. Trace elements			
2. Stability and ductility			
3. Future developments (powder metallurgy, dispersion strengthening, directional solidification and thermomechanical processing)			
4. Life prediction			
Subpanel on Hot-Corrosion			
1. Hot corrosion coatings			
Subpanel on Composites			
1. Characterization and processing			
Subpanel on Titanium			
1. Titanium fires			
2. Standardization action			
3. Life prediction			
4. Development of protective coatings			
5. Powder metallurgy			
6. Alloy and process development with high fracture toughness for ambient and intermediate temperature			
Subpanel on Nondestructive Evaluation			
1. Fundamental studies of phenomena potentially useful for NDE			
2. Development, application, and automation of new NDE techniques and tools, with attention to real factory and overhaul situations			

6.

	Urgent	Extremely Desirable	Desirable
Subpanel on Nondestructive Evaluation (Continued)			
3. Correlations between NDE measurements and part-life, in actual or simulated service			
4. Collecting and disseminating NDE information throughout aerospace industry, including instruction of material and design engineers in the use and power of NDE technology.			

APPENDIX B

AD HOC PANEL REPORT

NASA RESEARCH AND TECHNOLOGY ADVISORY COMMITTEE ON MATERIALS AND STRUCTURES

AD HOC PANEL ON EVALUATION OF AIRCRAFT STRUCTURES SUBCOMMITTEE RECOMMENDATIONS

Report of Meeting
September 20, 1971

NASA HEADQUARTERS

WASHINGTON, D.C.

NASA RESEARCH AND TECHNOLOGY ADVISORY COMMITTEE
ON MATERIALS AND STRUCTURES

AD HOC PANEL ON EVALUATION OF
AIRCRAFT STRUCTURES SUBCOMMITTEE RECOMMENDATIONS

REPORT OF MEETING
September 20, 1971

NASA HEADQUARTERS
WASHINGTON, D.C.

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NASA AD HOC PANEL ON EVALUATION OF AIRCRAFT STRUCTURES SUBCOMMITTEE RECOMMENDATIONS

Panel Members

* M. Jonathan Turner, Chairman	The Boeing Company
Edwin M. Ryan	Naval Air Systems Command
William T. Shuler	Lockheed-Georgia Company
Norman J. Mayer	NASA-Headquarters, OART

* Dr. Holt Ashley was originally appointed as Chairman. Following his transfer to another committee, his duties were assumed by the present Chairman.

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INTRODUCTION

The NASA Research and Technology Advisory Committee on Materials and Structures, at its meeting on May 5-6, 1971, established an Ad Hoc Panel to review the recommendations contained in a report of Ad Hoc Panels on V/STOL, Transonic and Hypersonic Aircraft Research prepared by a predecessor Subcommittee on Aircraft Structures and determine their pertinence relative to the following criteria:

1. They are indeed major barriers to progress toward NASA objectives.

2. They are receiving inadequate or no attention by NASA.

In preparation for such review, the NASA Research Centers were requested to submit their comments to the Panel concerning their evaluation of the referenced report. Members of the Advisory Committee were also requested to submit written comments to the Panel.

The Panel met at NASA Headquarters on September 20, 1971 to review the submitted comments as well as the original document. The information from which the Panel formed its review and drew its conclusions was not of sufficient detail or depth to warrant final and conclusive evidence that either of the evaluation criteria could be applied on an item by item basis. It was found, therefore, that the Panel adopted a more liberal interpretation of its assignment by providing a general evaluation of various areas and in addition by emphasizing a few new areas which appear to require investigation or expansion. Further in-depth evaluation of the NASA program as it relates to stated problem areas can be undertaken if the Committee should request such action, however.

EVALUATION

The Panel generally concurred that the recommendations presented in the reference document pertain to items which are major barriers to progress. The report continues to represent correct assessments of important current problems. In most cases, however, some NASA research effort was being devoted to the areas, and in many cases such effort appears to be adequate.

The following paragraphs contain specific comments to the Subcommittee Ad Hoc Panel report:

GENERAL

The Panel's review revealed several items applicable to all aircraft types which at present require either reiteration, or new emphasis. These were as follows:

Alleviation of Increasing Cost Trend

The Panel felt compelled to reiterate the statement that measures to arrest the rising trend in manufacturing costs are vitally important to the success of future programs. Since this complex and difficult problem is not mentioned in current activity reports, it may warrant the appointment of a panel to prepare specific recommendations.

Continuing Development of Advanced High Strength Alloys

This pertains particularly to heat treated titanium alloys.

Continuation of Fundamental Fatigue Research

Particular emphasis is needed on the development of design procedures for fatigue and corrosion resistant structure.

Lightning Strike Protection

It is felt that lightning strike protection should have been identified as a critical problem for applications of all-composite structures on any category of aircraft.

STRUCTURAL RESEARCH FOR V/STOL

As a general observation, the Panel concluded that development work on STOL and V/STOL aircraft is proceeding in the proper direction, in response to the CARD Study and through the cooperative program with the Army.

Further, since design criteria dictated by V/STOL missions and difficult noise suppression problems tend to substantially increase OWE, the exceptional payoff for application of composites on this class of vehicle should be strongly emphasized.

Fail Safe Engine Structure

In the area of damage tolerant structures it should be recognized that high bypass ratio engines for V/STOL aircraft present increased risk due to engine burst. Therefore, it is concluded that R&D effort is required on fail-safe engine parts and/or improved engine structural design.

Multiple Airfoil Flutter

Lift augmentation system of current interest justify a reemphasis of interest in multiple airfoil interference and related flutter problems.

Duct Dynamics

Past service experience with dynamic structural problems of inlets and ducts indicates that these kinds of problems are likely to create serious difficulties on V/STOL aircraft. Further study is needed to determine whether generalized design criteria can be developed to deal with these problems.

STRUCTURAL RESEARCH FOR ADVANCED TRANSPORT AIRCRAFT

Aerodynamic Data for Aeroelastic Analysis

It is believed that further comments are needed to emphasize the importance of continuing research on experimental and semi-empirical methods for obtaining aerodynamic data for aeroelastic analysis of specific aircraft configurations. Engineering work in this area has been heavily dependent on theoretical methods in marked contrast to the strong experimental bias of such traditional aerodynamic disciplines as performance and static stability analysis. Design of integrated active control systems intensifies the need for improved methods for determination of unsteady airloads due to control surface motions. It must be conceded that accurate direct measurement of all of the aerodynamic derivatives that are required for flutter or modal suppression system analysis is an unrealistic objective. However, the importance of the problem appears to justify a substantial effort to develop semi-empirical methods that are adaptable to specific configurations.

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Scaled Dynamic Wind Tunnel Model Development

Further improvement is urgently needed in methods of design and construction of scaled dynamic wind tunnel models to reduce technical risk in the development of transonic and supersonic aircraft. In the past the cost of advances in this technology have been derived largely from major aircraft development programs. This creates and unreasonable situation in which research on methodology is being performed concurrently with efforts to apply the new techniques in solving existing problems. Improvements in accuracy of structural simulation, reduced construction time, reduced cost, increased strength, and adaptability to structural modification are urgently needed. Computer aided techniques are needed to define structural changes to produce desired modifications of deflection influence coefficients. This would provide a technique for iterative improvement of a deficient model.

A low frequency stability augmentation system is needed for utilization in wind tunnel testing under simulated free flight conditions. This should remove serious limitations on flyable mass distributions that have been encountered frequently in flutter model testing.

HYPERSONIC AIRCRAFT CONSIDERATIONS

The Panel encourages the continued support of Hypersonic oriented research work and suggests that this subject be carried on the agenda of and be given particular attention in members' reports for future meetings.

PROPOSED RECOMMENDATIONS FOR COMMITTEE ACTION

The following recommendation is proposed for adoption by the Materials and Structures Committee:

Whereas the Ad Hoc Panel on V/STOL, Transonic and Hypersonic Aircraft of the NASA Research and Technology Advisory Subcommittee on Aircraft Structures presented its recommendations in a report dated May 1971, and

Whereas a Panel of the Committee on Materials and Structures reviewed such report, and has found, in most cases, that the areas identified in the report as important, represent goals to which NASA research is directed, and

Whereas certain of these areas need additional emphasis and certain new areas need to be included in NASA programs,

Therefore, it is recommended that NASA consider the present Ad Hoc Panel report of the Materials and Structures Committee as a supplement to and an updated version of the Subcommittee's May 1971 report since it represents current thinking as to important NASA objectives. It is further recommended that comment on the objectives and problems listed be included in future NASA Center reports to the Committee.

APPENDIX C

AD HOC PANEL REPORT

NASA RESEARCH AND TECHNOLOGY ADVISORY COMMITTEE ON MATERIALS AND STRUCTURES

AD HOC PANEL ON FRACTURE CONTROL

REPORT

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OCTOBER 1971

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NASA

REPORT OF NASA

AD HOC PANEL ON

FRACTURE CONTROL

10/8/71

L. P. Jahnke

L. P. Jahnke

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1.0 INTRODUCTION

BACKGROUND AND ASSIGNMENT

In April 1971 the newly created NASA Research and Technology Advisory Committee on Materials and Structures formed an Ad Hoc Panel on Fracture Control. The assignment of this panel was to define a program for NASA which would provide fracture mechanics methods applicable on a broad scale to aerospace structural design on a timely basis. It was requested this program include:

a) Procedures for producing improved design criteria,

b) Procedures for establishing acceptable and relevant test and inspection methods, and

c) Time scale for matching technology development with required readiness dates.

The Ad Hoc Panel met at the Lewis Research Center on June 10th and August 10th, 1971. The members were:

LP Jahnke (Chairman)	General Electric Company (and liaison representative of the parent M&S Advisory Committee)
CF Tiffany	Boeing Company (on Air Force assignment at present)
R. Heitzmann	Grumman Aerospace Corporation
EK Walker	Lockheed Aircraft Corporation
WF Brown	NASA-Lewis Research Center
GE Bockrath	McDonnell-Douglas Astronautics Company
HG Popp	General Electric Company
RR Heldenfels	NASA-Langley Research Center

Two of the members (Heldenfels and Brown) had recently served on a similar committee established by the Deputy Administrator of NASA to study NASA structural failures that had occurred in the past few years and to determine what additional research was needed to reduce the risk of future failures. This NASA Ad Hoc Committee on Failure of High Strength Structural Materials issued a report in August 1971 which was of considerable help to the present Ad Hoc Fracture

Control Panel. (Their report contains details and discussions which reinforce this text and should be read.) With few exceptions - these being mainly in emphasis and concepts of implementation, the recommendations of these two ad hoc groups are very similar. In addition, Mr. Heldenfels participated in a USAF study of The Structural Integrity of Current and Future Air Force Systems, completed in July 1971, which also provided insight as to problem areas. There is widespread agreement among informed materials and structural experts that significant improvements are needed, both in the application and also in the further development of fracture control technology. The basis of this need deserves discussion.

MOTIVATION AND JUSTIFICATION

Justification for greater resources to be assigned to improve both the use and the capabilities of fracture control technology is established by two situations. The first is the appalling cost and delay caused by past, avoidable failures. The second is the increased challenge created by our desires for improved future systems.

The previous NASA Ad Hoc Committee traced 231 NASA structural failures in the past five years and found that very few structural failures could be attributed to deficiencies in technology. However, these few were very serious and had a large impact on both program cost and schedule. The great majority not attibutable to technological deficiencies of high strength materials were traceable to: (1) inadequate dissemination or use of available knowledge and data, or (2) unrealistic assessments of technology, cost, and schedule in initial program planning.

The present Ad Hoc Panel agrees with this judgement and also believes the present state of this technology is incapable of handling the future desires of this country for aerospace vehicles with improved capabilities and even greater reliability.

Past Failures - The record provides evidence of large numbers of structural failures due to fracture and fatigue effects. These failures have no doubt resulted in high costs in terms of loss of equipment and program delays. The record does not provide reliable figures for estimating these costs, but their gross values are no doubt in the tens of millions and probably higher, considering both the direct costs of lost hardware and the associated indirect costs from delays and problems solving efforts. A few examples of items in prominent programs in both the aeronautical and space fields are cited:

1) F-111 - the use of high strength, low toughness, flaw-sensitive steel for the monolithic carry-through structure resulted in failures which led to additional program delays.

2) NASA 260 inch motor - the use of improper welding processes and inadequate nondestructive test methods resulted in a hydrotest failure of a motor case and a complete loss of the case.

3) NASA SPS Tank - the presence of machine tool marks combined with an unexpectedly aggressive influence of methanol on Titanium 6-4 alloy resulted in the destruction of Apollo Service Module No. 17.

4) LM Program Tanks - undetected, subsurface metallurgical defects in Ti tanks, stress corrosion in an Aluminum alloy cover, and inadequate welding techniques and inspection methods resulted in tank failures and caused the rejection of the remaining tanks due to reliability concerns.

Future Challenges - In the last few decades payload and life improvements in aerospace vehicles have come in large part from the use of higher strength materials, at higher operating stresses. Within any alloy class, higher strength materials have lower fracture toughness, which is a measure of the ability to tolerate flaws created during manufacture or service. It is abundantly apparent to experts in the field that in many applications we have reached the end of vehicle performance improvements through the use of increasingly stronger metals. Based on our present knowledge, in such applications stronger metals cannot be used with adequate reliability in view of the flaws which can indeed exist in structures. Thus a very real and imposing barrier has been reached which will only be circumvented by the application of additional resources to research for knowledge and the development of new fracture control tools for the use of the aerospace technical community. We can design and build useful and safe aircraft now, by the thoughtful use of existing fracture control knowledge. But we cannot build much better ones without major additions to the technical foundations of this technology. The rest of this report establishes more firmly the nature of this problem and the directions which must be followed to accomplish this.

2.0 SCOPE OF PROBLEM

From the foregoing discussion it is apparent that there is a need to substantially improve both structural integrity (i.e. the prevention of structural failures affecting safety of flight) and structural durability (i.e. increasing service life and reducing the amount of unscheduled structural maintenance required).

The total life of a tension-loaded structure can be thought of as being composed of the time required to initiate cracking, plus the time required to propagate the crack to critical size. From the standpoint of structural safety, it is both prudent and necessary to assume that the initiation phase may be zero (i.e. cracks or crack-like flaws may be initially present in the structure). If it is a single loadpath structure without crack arrest capability (e.g. most pressure vessels), it is necessary to insure that the initial flaws do not grow to critical size at anytime during the required life of the structure. This has been called "safe-life design". An alternate approach is currently being referred to as "damage tolerant design". It insures safety if the structure possesses crack arrest capability; for example, the tear stoppers in a pressurized fuselage, and/or multiple load paths. If after a failure of a single primary element, the remaining structure possesses adequate strength for a specified load-time period, the structure is "fail-safe".

From the standpoint of increasing structural life and reducing structural maintenance (and the associated economic and operational problems) it is necessary to eliminate, or at least delay, the deterioration of protection systems, corrosion pit formation, and initiation of cracking.

There are numerous interrelated factors that contribute to achieving a long-life structure. It is difficult (if not impossible) to single out any one factor as being of dominant importance. Neglecting or paying inadequate attention to any one (or not recognizing the importance of their interrelationships) can result in a serious deterioration of life and in some cases endanger safety of flight. For example, nondestructive evaluation will not prevent failures if the techniques used cannot reliably detect the flaw that must be detected; careful stress and fatigue analyses will not prevent or delay crack initiation if the "as fabricated" structure contains large built-in installation stresses; and the use of residual stresses to improve fatigue life are of questionable value, if, as a result, the susceptibility to stress corrosion cracking is increased.

During recent years, the need for higher performance and longer life flight vehicles has aggravated both the structural integrity and structural durability problems. In addition, limited budgets and tight schedules have compounded the problem. The higher performance requirements have resulted in use of higher strength materials, higher operating stress levels, higher wing loadings, and compact structural arrangements that often require high load concentrations. In addition, environmental exposures have become more severe.

Typically higher strength materials have reduced fracture toughness and usually reduced resistance to environmentally induced subcritical crack growth. This combined with the increased stress levels have drastically reduced both the allowable initial and critical flaw sizes. Also, in some cases, the higher stress levels have resulted in reduced fatigue life. Higher wing loading requirements and thinner wings have resulted in the use of thicker structural members, which are more prone to plane strain fracture and have smaller critical flaw sizes. The use of compact structural arrangements have resulted in the use of complex, difficult to inspect, and difficult to analyze geometries that can be extremely prone to fatigue cracking because of the local stress concentrations involved. The more severe environmental exposures have placed additional emphasis on more accurate thermal stress analyses and protection against rain, hail, and bird damage and environmentally induced cracking.

The inherent nature of the aerospace system which puts an upward pressure on performance and a downward pressure on cost tends to lead to a reduction in structural integrity and durability. It is clear that this trend must be stopped and, if possible, reversed.

In this report, primary attention is directed toward the structural integrity or safety aspect of the total life problem. In this respect, the damage tolerance capabilities of structures is predominant and fracture mechanics techniques are of primary importance in establishing this behavior. Subsequent sections discuss the specific problems involved, provide an assessment of the technology, and attempt to provide insight into the needed research efforts.

Recent interest in composite materials for aerospace structures add further complications to the fracture control problem. Composites do not, however, represent a significant percent of the available structural materials now or in the immediate future. Considering the immensity of the fracture control in monolithic metal materials, composite materials are not included within the scope of this report. General discussion of the failure problems in composites is covered in the NASA Ad Hoc Committee report on Failure of High Strength Structural Materials.

3.0 STATEMENT OF PROBLEM

INTRODUCTION

Achievement of the required service life of aerospace vehicles is dependent upon the proper consideration of fatigue and fracture in the design, construction, and operation of the airframe, engines, and equipment. All parts experience cyclic loads and environmental conditions that may cause fatigue and other cracks to form. These cracks or flaws develop and grow during operations and can cause fracture unless corrective action is taken. Such considerations are especially important when high-strength materials are used in weight-critical vehicles. This section discusses the three fundamental aspects of fracture control (initial flaw size, subcritical flaw growth, and critical flaw size), their interactions, and their relationships to design and operation of vehicles.

INITIAL FLAW SIZE

The first step in establishing the remaining service life of a vehicle is identification of all significant flaws. Flaws may be introduced during manufacture or develop in service due to fatigue, corrosion, accidents, or battle damage. Quantitative assessment of the size, shape, and location of flaws, which include cracks, voids, material contamination, and areas of surface distress, is required. Such determinations must be made for the materials, fabricated components, and the assembled vehicle before it is placed in service and at intervals during its life. Nondestructive evaluation (NDE) techniques are required to accomplish this identification. On some structures, some areas may be unaccessible to nondestructive inspection methods and periodic proof tests can be useful to establish initial flaw size. The minimum defect size which can be detected reliably has a direct effect on the structural weight required and on the risk of structural failure.

SUBCRITICAL FLAW GROWTH

Knowing the size of an existing flaw and the critical flaw size for a part, the life of the part is determined by the rate at which normal service loads cause the crack to grow from the initial to critical size. However, uncertainties and prudence require that at some fraction of this life (1/2 to 1/8 or less depending on circumstances) the part be discarded or inspected, repaired, and returned to service. The rate at which a flaw will grow depends on the size of the flaw, the stresses to which the part is subjected, crack growth resistance of the material, and the environment. Structural configurations affect crack growth rates through their influence on the stress field around a crack and certain types of stiffening can provide substantial reductions. Predictions of crack growth require test methods, data, and analytical procedures for design and analysis of structures. To reduce weight of future structures, ways should be found to increase the crack growth resistance of materials and structures. Current knowledge of the relationship between material microstructure and subcritical crack growth is too meager to form conclusions as to how crack growth resistance might be increased.

CRITICAL FLAW SIZE

Safe operation of a vehicle requires a quantitative determination of the residual static strength of a structure containing a flaw. Associated with each loading situation, there is a minimum size flaw which will cause complete failure of a structure or structural element. The minimum flaw size associated with the highest expected load is called the critical flaw size. This critical flaw size for a material depends on a material property called fracture toughness. Unfortunately, fracture toughness, and therefore critical flaw size, are usually low for high strength materials. Structural configurations also affect the residual strength of parts in that stiffening elements can arrest the sudden crack growth associated with material fracture. To predict the residual strength of damage tolerant designs or the safe life of other designs, it is necessary to calculate the critical flaw sizes from appropriate fracture data and design stress analyses. To reduce weight of future structures without a sacrifice in reliability, techniques must be devised to increase the fracture toughness of materials and the crack tolerance of structures.

INTERACTIONS

Loads and environments encountered in service are usually complex and data, test methods, and analytical procedures must account for such effects in the determination of life and residual strength. Environmental factors such as humidity, salt spray, and other corrodents can cause cracks to grow under sustained load, and can cause the rate of crack growth to increase under cyclic loads. Elevated temperatures can reduce all material properties, accelerate corrosion effects, and introduce creep as an additional complication. The variations of load amplitude that are common in most operating environments affect the rate of crack growth in a very nonlinear way, particularly when occasional high loads are encountered. In addition, the size and thickness of a part may also affect the critical flaw size and growth rate.

DESIGN IMPLICATIONS

Fracture control is so complex and its interactive effects on structures are difficult to define. However, a simplified integration of the influence of the basic factors provides some insight into their significance for various design situations. The basic design requirements will be to achieve a given life or inspection interval under a particular load spectrum. The NDE or proof test capabilities employed will establish the initial flaw size. Then, for a given material, a limit design stress can be selected. The relative importance of ultimate strength, fracture toughness, crack growth resistance, and fatigue life of the unflawed material depends on each particular combination of initial flaw size and required life. If the required life is long and the initial flaw size is small, resistance to crack growth is most important. For large initial flaws and short required lives, fracture toughness is of greatest concern. When the required life is short and initial flaws are small, the basic ultimate strength governs design. Generally, long lives are not achievable if initial flaws are large.

If the material and structural configuration are fixed, low design stresses and hence higher weights are required to achieve long life or to tolerate large initial flaws. Lower weights can be achieved if better NDE, superior materials, or improved structural configurations are used. In selecting a material, the relative significance of density, ultimate strength, fracture toughness, and crack growth resistance of each candidate material must be evaluated for the design situation. For example, in long-life structures, the crack-growth-resistance-to-density ratio will be the property of most importance and the material selected need only have some reasonable value of strength and fracture toughness. Future alloy development might profitably reduce strength, if necessary, to increase crack growth resistance. New research is needed to supply the metallurgical knowledge and techniques for such developments. Similar guidelines for NDE and structures research can be developed for each design situation by related tradeoff studies.

OPERATIONAL ASPECTS

The ultimate purpose of fracture control is to provide a reliable structure, thus assuring that the vehicle will complete its required missions without a structural failure. Two general concepts are employed for this purpose: safe-life and damage-tolerant (fail-safe).

The safe-life design concept requires that a critical size flaw will not develop during the required life. This implies that new parts do not contain significant cracks. Generally safe-life parts are inspected during service and a safe-life part may be used beyond its design life if NDE or proof test can establish that no significant flaws are present. Many parts (e.g. landing gears, turbine disks), because of their nature, must be designed on a safe-life basis. The pressure to reduce the weight of such parts plus the variability in strength, resistance to crack growth, and NDE could result in inadequate reliability if initial flaws are not properly considered.

The damage-tolerant (or fail-safe) concept recognizes that cracks will occur and a schedule of systematic NDE is employed to locate cracks. These cracks are then repaired as necessary to provide the required structural integrity until the next scheduled inspection. The sensitivity and timing of NDE is determined by the residual strength and crack growth characteristics of the structure. An essential feature of damage tolerant design is a structural configuration that contains crack growth arresting features (tear stoppers) and multiple load paths (redundancy) that make it "fail-safe".

The design philosophy, inspection methods, and schedules must be selected during the design process and the related weights, costs, and maintenance time become important considerations in total system definition.

PARAMETRIC STUDIES

The complex interaction of many design, manufacturing, material, inspection, and operating factors determine the best solution to structural integrity and fracture control. The actual pre-eminence of one or a few of these factors in a particular structure is not always obvious. However, parametric design studies can reveal the relative importance of these factors for particular applications and thus provide guidelines for selecting research areas, establishing priorities through identification of technology deficiencies, and identifying direction for the greatest potential improvement. Since cyclic loading is the major consideration in establishing the useful service life of most parts of aerospace vehicle structures, fatigue and fracture are the prime factors in any parametric study. A discussion of one such parametric study is included in the Appendix.

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4.0 CONCLUSIONS AND RECOMMENDATIONS

In the preceding discussion, technical problems and current gaps in fracture control technology have been described. The following conclusions and recommendations identify more specifically areas in which the technology is clearly deficient and must be enhanced by research. Filling these technological gaps will require substantial resources in manpower and dollars for in-house and contract research for a number of years. Consequently, NASA should concentrate its effort on those aspects of the areas enumerated below that promise the greatest potential payoff for vehicles of greatest concern to NASA.

PARAMETRIC STUDIES

Conclusions

1. The complex interaction of many design, material, manufacturing, inspection, and operating factors must be considered in determining the best solution to fracture control while still meeting performance requirements. Parametric design studies can reveal the relative importance of these factors for many structural applications. Thus they can provide guidelines for selecting research areas, establishing priorities, through the identification of technological deficiencies and determining direction for the greatest payoffs from developments in NDE, analytical methods, design criteria, alloy development, structural configuration, and operational practice. Furthermore, the insight provided by these parametric studies relative to deficient areas (when coupled with NASA's long range planning for vehicle development) will help establish time tables for scheduling the necessary development of fracture control technology.

Recommendations

1. Parametric studies should be made to identify areas of both technological deficiencies and opportunities in a fracture control system. These studies will show the relative importance of the factors involved in structural design and operation and will help establish directions, schedules, and priorities for research.

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STANDARD TEST METHODS

Conclusions

1. The utility of current fracture data in material selection, design, and quality control is limited. Current standard test methods are limited to measuring plane strain fracture toughness with difficult testing requirements which, at times, are impossible to meet. Many fracture prevention situations in aerospace structures involve gross plastic deformations which are outside the assumptions of linear elastic fracture mechanics. Such situations are encountered when the material is sufficiently tough and the section sufficiently thin that failure stresses in the presence of cracks are not relatable to plane strain fracture toughness. A new approach, either theoretical or empirical, is needed to assess accurately fracture behavior under such environments.

2. In many applications, standard plane strain fracture toughness test methods are too restrictive and thus are of only marginal value in material development, screening, or quality control. Current methods are too costly and often the plane strain conditions are literally impossible to meet.

3. Subcritical crack growth resistance is emerging as the prime material property in fracture control of aerospace structures, particularly those with long life requirements. Included in subcritical crack growth is crack extension under both static and cyclic load and the effect of aggressive environments on crack extension.

Recommendations

NASA should strengthen its effort in the following areas and implement developments through the E-24 Committee of ASTM.

1. Effort should be directed at developing an approach to generate meaningful test methods and data correlation procedures for practical design situations which involve gross plastic deformations beyond the limitations of elastic fracture mechanics.

2. NASA should direct research and effort in cooperation with ASTM to develop standard test methods for screening metallic materials for their fracture properties. The methods must be responsive to the limited material thickness limitations necessary in material development and product acceptance testing.

3. NASA should develop standard test methods for evaluating subcritical crack growth resistance of materials under relevant cyclic and static conditions including environmental effects.

GENERATION OF DATA

Conclusions

1. The application of damage tolerant design approaches to aerospace structure is greatly hindered by the lack of data for fracture resistance of materials. Extensive data covering propagation behavior under static and cyclic conditions, along with pertinent environmental effects needed for complete flaw growth analysis, are generally not available. Data of this type are needed if fracture control is to become standard practice. If specific systems contractors are to generate the data to meet their requirements it is doubtful that it would be of uniform standard quality and available for the general use of the aerospace industry.

Recommendations

1. NASA should establish programs with the objective of the accumulation of a bank of crack propagation and fracture data which would be useful in materials selection and design. The utility of these data will be greatly increased if they are gathered using standardized test methods. Data should be generated on materials of interest to NASA vehicles and on the following metal characteristics: 1) plane strain fracture toughness, 2) constant amplitude cycle flaw growth, and 3) sustained load flaw growth under the presence of commonly encountered aggressive environments, including gaseous hydrogen.

COLLECTION AND DISSEMINATION OF DATA

Conclusions

1. Failure experience within the aerospace industry has shown that the technology necessary to prevent many of the failures during the last decade was available but had not been incorporated into adequate failure prevention efforts. Collection and dissemination techniques on fracture information and data are lacking in that pertinent information is not reaching the aerospace structures contractors. Currently, there are general data dissemination activities (government agencies' technical reports, technical society reports and publications, and DOD material data information centers) which include fracture information along with other data but these agencies have proven to be inadequate to disseminate the information on a timely basis to the

ultimate user, the contracted structural designer. Lack of communication within and between government agencies and industrial contractors has prevented the development of unified fracture control practices; the sharing of timely, costly materials data; and often has resulted in duplication of effort. Future demands for improved fracture control coupled with higher performance vehicles make rapid dissemination of information even more critical.

Recommendations

1. As part of its overall Fracture Control Program, NASA should establish a fracture control information center which will emphasize the aspects of fracture control information and data which are not emphasized by existing government and society functions. Specifically, this information center would:

a) Collect all reports and documents related to fracture control including crack propagation data, fracture toughness data, methods for test, flaw tolerance analysis, nondestructive test methods, and structural failures.

b) Publish a periodical acquisition list containing appropriate title and author information and a verbatim abstract extracted from the document.

c) Provide a suitable computerized materials fracture data retrieval system, coded to allow data searches to be made from a broad family of key indicators such as alloy identity, crack propagation, K_{IC}, analysis methods, NDT, and etc.

d) Provide the facilities for the reproduction and distribution of full copies of original documents to all government agencies and their contractors upon request.

It is recommended that this program be coordinated with all DOD agencies to ensure that data generated in contracted design programs are made available rapidly.

2. Through its role in the fracture information data function, NASA should encourage the free flow of fracture information on failure prevention procedures and materials data. This could be accomplished by freely disseminating reports and conducting periodic technology symposiums held at the NASA Fracture Information Data Center.

NONDESTRUCTIVE EVALUATION

Conclusions

1. In any failure prevention scheme, nondestructive evaluation is the final recourse in the prevention of structural fracture. Failure experience has indicated it also is one of the weakest technology areas to achieving fracture control. A lack of confidence in NDE which prevails through the industry is well founded. Little concrete evidence exists to define the real capabilities of NDE to define sizes, acuity, and types of flaws from inspection indications. Furthermore, little discipline has been evident within this technology to establish standards and specifications to control a guaranteed sensitivity or capability. Lack of firm direction seems to be a major hindrance to adequate NDE technology development and control.

2. Even if current NDE capabilities can be accurately defined and controlled, it is obvious that these sensitivity levels are inadequate for some future structural requirements. In fact, some current design criteria may have extended beyond the justifiable limit supported by verified NDE capability. Without NDE improvement, the industry may have to avoid using high strength materials or not take advantage of their higher strengths.

3. The ability to nondestructively classify flaws in structures other than cracks and voids is also a critical need. Weak or brittle areas (segregation, grain boundary films, local contamination, etc) and surface distress (embrittlement, phase transformation, surface finish, residual stress, etc) add to the demand for reliance on NDE for fracture control. NDE methods are inadequate to assess most of these flaws and reliance must be placed on dubious process controls.

4. Insufficient attention has been given to the requirement for NDE throughout the development stages of aerospace structures. Operating stresses, manufacturing processes, and assembled configurations often are finalized before NDE requirements are incorporated.

5. Many current NDE systems rely on human operator proficiency and as such are of questionable reliability.

Recommendations

1. An organizational focal point should be established within NASA to act as a central coordinating point for NDE activities as related to failure prevention. Its function should be to emphasize:

a) NDE standardization
b) Definition of NDE capabilities
c) Development of improved and new systems
d) Authoritative reference source
e) Identification of needed additional research

2. Research efforts should be conducted both in-house and at external sources to define the capabilities of current NDE systems as to their abilities to classify defects in size and acuity. Emphasis should be given to the capabilities to detect tight cracks or crack-like flaws. From these efforts consistent NDE standards should be developed for quality control and verification purposes.

3. Research efforts should be directed at improved NDE systems for both cracks and other potential flaws (metallurgical and surface integrity) which could degrade strength and be active in a failure process.

4. In its role in procurement of aerospace structures, NASA should establish a set of NDE requirements on new systems. These would include:

a) That NDE requirements are an integral part of the initial design considerations, both for initial and overhaul inspections.

b) That verification of NDE claims are substantiated. This would include probability of detection versus NDE sensitivity, demonstration of detectability of maximum permissible flaw size, and establishment of NDE standards and specifications.

5. NASA should develop practical methods for automating the entire NDE process to reduce reliance on human proficiency.

METALLURGICAL DEVELOPMENT

Conclusions

1. Disastrous experience with low toughness materials in structural applications is causing a reassessment of the wisdom of using new materials which offer apparent strength or weight advantages, but with lower toughness. The general inverse relationship between toughness and

strength for most material systems suggests quite clearly that the aerospace industry is approaching a barrier to further improvement of materials properties. Moreover it is probable this barrier is immediately before us and further advancements will require metallurgical innovations to improve fracture resistance properties.

2. These innovations will be particularly difficult to achieve because of lack of fundamental understanding of the relationship of microstructure characteristics and crack propagation. Until recently, little motivation for improved toughness was provided to the materials industry. Without this emphasis, metallurgists have not developed adequate knowledge and tools for producing improved toughness materials or for controlling toughness in existing materials. Particularly deficient is the knowledge on the metallurgical aspects which control cyclic stress flaw growth and how it is effected by aggressive environments.

Recommendations

1. Since the lack of understanding of the effect of metallurgical structure on fracture toughness represents a barrier to achievement of the next generation of high strength aerospace materials and proper use or control of existing materials, a sustained effort to develop the needed technology is required. Such an effort should be conducted in an environment where research and development on mechanical behavior and nondestructive examination would be active. Close interaction of these disciplines is a necessity for effectiveness. Specific areas for directed effort are:

a) Develop a basic understanding of the role of metallurgical structure in the fracture behavior of critical aerospace alloy systems. These would include the high strength systems of the aluminum, titanium, nickel, and steel alloys. Studies should include fracture toughness as well as subcritical flaw growth under static and dynamic loading in typical environments.

b) Develop relationship between toughness, crack growth resistance, and other mechanical properties which could be of practical use as quality control tools.

c) Initiate alloy development activities in critical alloys systems to provide new, high strength materials with improved toughness and crack growth resistance. Knowledge gained from item (a) should guide these efforts.

It is recommended that a significant share of the total effort on metallurgical research be conducted at external (to NASA) research and development facilities. Such sponsored effort is particularly important in the case of metallurgical research since it would help to establish a desired broad industry/university technology base in this field.

ANALYTICAL METHODS

Conclusions

Cracks or crack-like flaws may exist in aerospace hardware as produced, or may develop in service. The possible existence of such flaws must be considered in designing structures to produce damage-tolerant vehicles. Available methods for analysis of such problems are inadequate in the following areas:

1. Linear elastic fracture mechanics has been developed for the analysis of structure-containing cracks. It is a theory of brittle failure and it applies only under conditions of plane strain constraint and small scale yielding at the crack tip. An elastic-plastic fracture mechanics method needs to be developed to provide quantitative information about the effect of cracks in tough materials.

2. Empirical methods have been developed for the analysis of tough, ductile structural materials under conditions where linear elastic fracture mechanics is not applicable. However, severe limitations hinder their widespread use.

3. Stress intensity values of accuracy useful in design can be determined for only a few design situations which are largely for brittle materials in simple geometric configurations. Accurate methods for determining stress intensity values are not available for complex geometrical configurations and loading conditions which are typical, for example, of engine hardware, forgings, and integrally-stiffened structures.

4. Accurate methods are not available for determining the change in flaw growth characteristics or in defect tolerance, which results from pre-stressing at higher than operating stresses.

5. Adequate methods have not been developed for determination of damage, or predicting crack growth under cyclic and/or sustained loading in practical situations involving the effects of cyclic load profile, temperature, and environment.

6. It is assumed, on the basis of a small amount of test data, that the strength of cracked spherical and cylindrical pressure vessels can be determined from tests of flat, cracked test specimens. Although the relationship should be well established for a variety of materials, there are no experimental programs planned or in being to establish the relationship.

Recommendations

1. An elastic-plastic fracture mechanics method should be developed to provide useful quantitative design information for tough materials and practical design situations.

2. Development of a useful elastic-plastic fracture mechanics method may be a slow, long-range project. In the meantime, refinement and expansion of existing empirical methods or development of new methods should be supported.

3. Analytical methods should be developed for determining stress intensities with useful accuracy in complex geometrical configurations and loading conditions. Such methods must be useful for the analysis, for example, of engine hardware, forgings, integrally stiffened structure, and other details of complex shape.

4. A program should be initiated for the purpose of improving the defect tolerance of potentially flawed hardware. Pre-stressing at higher than operating stress is known to be beneficial but also risky. An analysis method should be developed to show the effect of residual stresses and plastic deformation at the crack tip on flawed structure.

5. Methods should be developed for determining life of structure under cyclic and/or sustained loading in practical situations. The methods must consider the effects of loading profile, single and multiple high loads, stress ratio, temperature, time of loading, and environment. The methods must be useful for predicting crack growth rate in typical situations.

6. Pressure vessels and other hardware are designed using data obtained from cracked, flat tensile test specimens. A program should be initiated to establish the validity of using flat specimen data for the design of curved structure. If needed, a method should be developed for correcting flat plate data to make it useful for design.

INTERACTION STUDIES

Conclusions

1. The variations of load amplitudes and a number of environmental factors such as humidity, salt spray, and elevated temperatures can interact in very complex and nonlinear ways to affect crack growth and critical flaw sizes. Experimental data on the effects of interactions of potential combinations of important parameters is grossly inadequate for satisfactory structural design.

Recommendations

1. Investigate interaction of various stress levels of a spectrum loading including single and multiple high loads, the influence of stress ratio, and of other spectrum parameters. These studies should evaluate both the effect on crack propagation rates and on critical crack size.

2. Study interaction of environment with spectrum loading parameters, particularly the consequences of compressed time testing. The effects of environments such as high humidity, salt water, fuels, and others should be evaluated as possibly altering the influence of spectrum load parameters on crack growth and on critical crack lengths.

3. Use these studies as a basis for analytical studies recommended in the previous section.

5.0 SUMMARY

From the preceding discussions it is apparent that significant gaps exist, both in the intelligent application of existing knowledge and in our projected ability to provide more efficient aerospace vehicles with lower risk of unexpected and costly failures.

These gaps must be filled by a coordinated, aggressive attack, substantial increases in resources, and an implicit program continuity for several years. The main gaps are summarized below.

1) Parametric design studies of pertinent vehicles must be done to establish research priorities and the mix of disciplines required to form the most effective attack on the following facets of the fracture control technology.

2) Standardized test methods must be established for the determination of fracture properties in cooperation with ASTM.

3) Fracture data must be generated on a variety of modern aerospace alloys using these standardized tests.

4) A rigorous system must be created to assure that fracture control information is collected and disseminated to all appropriate groups in industry and government.

5) The true capabilities of current nondestructive evaluation methods must be firmly established and research done to extend these capabilities.

6) The relationship of metallurgical structure to fracture behavior must be established and guidelines for alloy development defined.

7) Analytical and empirical methods must be developed which are capable of dealing with elastic-plastic design situations plus complex geometries and loads.

8) Experimental work must be undertaken to define the interactions of corrosive environments, overloads, time at temperature, and dynamic stress fields upon crack growth.

APPENDIX

PARAMETRIC APPROACHES TO FRACTURE CONTROL

Parametric studies can be made to identify deficient areas and to indicate maximum payoffs. They can show how fatigue and fracture characteristics of materials influence structural weight of a typical component designed to some life of (N) load cycles. The design dictates the use of the highest allowable design stress (σ) that will provide the required life and thereby achieve the lowest weight. Material characteristics that determine the design stress are ultimate strength (σ_u), fracture toughness (K) and crack growth resistance (C). Another design parameter is the initial flaw size in the structure (a_o) which is determined by the flaws that can be found in the material, structural elements and components, and in the assembled vehicle by non-destructive evaluation techniques.

Figure 1 is a three-dimensional plot that shows allowable design stress as a function of life and initial flaw size for a particular material. In addition, areas on the curves have been labeled to indicate which material characteristic is predominant. The design stress can thus be determined from such a collection of data. Materials can be compared to determine which produces the least weight design by examination of the ratio σ/ρ; the highest value of design stress (σ) divided by density (ρ) gives the lowest weight.

Figure 2 shows the a_o versus N plane of figure 1 and the projections on it of the boundaries between the labeled areas. This figure provides further insight into which material characteristic is most important if the design requirements fall into a particular life-initial-flaw region. A representative NDE limit has been added to show that there is a strong interaction between material properties, NDE capability, and design requirements. The most profitable directions for future material improvement can be determined by these interactions. For example, in many long life aircraft applications (such as point A), an increase in crack growth resistance (C) of materials could make the greatest contribution to increasing service life without increasing weight.

Figure 3 is a three-dimensional plot of the three material properties (σ_u/ρ, K/ρ, C/ρ) that effect structural weight in the simplified situation under discussion. The length and direction of the vector locating the characteristics of a given material determine the types of applications for which it is the best suited. Material A would be superior for a design mission which emphasized cyclic crack growth, while material B would be superior for a mission where limit load requirements are paramount. Obviously, consideration of the application will show the most profitable direction for improvement of these materials properties — if all can't be increased, one or more may be at the expense of others.

Figure 4 shows the $^{\sigma\mu}/\rho$ - K/ρ plane of Figure 3. Also shown is a line indicating the NDE capability which is established by the critical applied stress for a given toughness at the limit of NDE detectability. Material A has high strength but this strength is not usable in an application in which K is important. For such applications, the K value should be increased and would pay off in structural weight reduction even if σ_u was reduced somewhat in the process. However, material A has characteristics which permit the use of stress fields (proof tests) for NDE purposes. Material B, on the other hand, does not have enough strength for full use of its toughness and proof tests are not a suitable NDE technique in its applications. Some of its toughness could be sacrificed when increasing its strength. Two arrows on the figure indicate profitable directions for improving each of these materials; the third arrow indicates improvement from NDE research and development.

These are but a few examples of parametric studies of the interactions of the many factors effecting fracture control. Each facet of the problem is affected by the many other complicating effects so that data and analyses required in an actual case are much more complex than indicated in the simple examples and discussions. However, they help demonstrate the breadth of the problem and bring deficient areas into clearer focus.

APPENDIX D

AD HOC PANEL REPORT

NASA RESEARCH AND TECHNOLOGY ADVISORY COMMITTEE ON MATERIALS AND STRUCTURES

AD HOC PANEL ON COMPOSITE MATERIALS APPLICATIONS

Report of Meeting
July 13, 1971

LANGLEY RESEARCH CENTER
HAMPTON, VIRGINIA

NASA RESEARCH AND TECHNOLOGY ADVISORY COMMITTEE ON MATERIALS AND STRUCTURES

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REPORT OF MEETING

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LANGLEY RESEARCH CENTER
HAMPTON, VIRGINIA

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and

AGENDA

July 13, 1971 Meeting

Langley Research Center, Hampton, Virginia

AD HOC PANEL ON COMPOSITE MATERIAL APPLICATIONS TO AIRCRAFT STRUCTURE

NASA AD HOC PANEL ON COMPOSITES

ATTENDEES

Panel Members

William T. Shuler, Chairman	Lockheed-Georgia Co.
Arthur August	Grumman Aerospace Corp.
Kenneth Boll	Pratt & Whitney
Charles W. Rogers	General Dynamics/Fort Worth
Frank D. Cherry	McDonnell-Douglas, St. Louis
George P. Peterson	AFML-WPAFB
Robert Berrisford	USA AMRDL Eoslos
A. P. Cowles	NAVAIR, Washington, D.C.
Richard A. Pride	NASA-Langley
Robert H. Johns	NASA-Lewis
William A. Wilson	NASA-MSFC
Norman J. Mayer	NASA-Headquarters, OART

Guests

Dr. George W. Brooks	NASA-Langley
William A. Brooks, Jr.	NASA-Langley
Herbert F. Hardrath	NASA-Langley
Norman G. Peil	NASA-Headquarters, OMSF

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INTRODUCTION

The NASA Ad Hoc Panel on Composites was established by the NASA Research and Technology Advisory Committee on Materials and Structures to examine the present program on composites for aeronautical application and recommend a future program. The Panel initially consisted of industrial and research institutional members and a representative from the Air Force Materials Laboratory. Following its report to the Committee, the Panel was expanded to include other DOD and NASA members in order to provide a status report on the various organizations' programs. A second meeting was then held at the Langley Research Center to respond to the specific requests of the Advisory Committee. This report describes the discussions of the second meeting and the Panel's recommendations to the Committee concerning the aeronautical program.

REPORT OF MEETING

The Panel met at the Langley Research Center on July 13, 1971 from 9:00 AM to 4:30 PM.

Review of Panel Responsibiility

Mr. Shuler, Chairman of the Panel, reviewed the objectives of the meeting by reading the recommendations of the NASA Research and Technology Advisory Committee on Materials and Structures. These were:

1. Review of the FY 71, 72, and 73 NASA, Navy, Army, and Air Force composite materials applications programs.

2. Definition of the present NASA role in composites in terms of broad objectives.

3. Recommendation for a future NASA role in composites for civil and military aircraft application, levels of funding, and specific tasks to be undertaken.

As a step toward these objectives, the Government members of the Panel were requested, prior to the meeting, to prepare lists of present and planned tasks or projects concerning the development of composites for aircraft application in their organizations for FY 71, 72, and 73 with applicable funding.

Members of the Advisory Committee were also requested to furnish information pertinent to the Panel's objectives, particularly regarding civil aircraft applications and studies. Members of the predecessor NASA Subcommittee on Aircraft Structures were also contacted for information.

Review of Programs

The composite program information requested from the NASA, Air Force, Navy, and Army Panel members was reviewed by the Panel. The distribution of this effort among major areas of emphasis is shown in Fig. 1-3. All agency program data revealed a predominance of effort on military aircraft structural applications. Research generally applicable as a fundamental technology in materials development and structural analysis was the next major area.

The NASA data included projects applicable to the Space Shuttle program which represented the total Marshall Space Flight Center effort and a large part of the Lewis Research Center effort.

Mr. Peterson noted that the Air Force program did not show all of the planned effort in the missile area which would approximately double the funding indicated for this item. He also stated that more emphasis would be placed on conceptual design in the near term. The USAF composites program for manned aircraft (exclusive of missiles) was the largest of the DOD programs, in the order of approximately $14-18 million per year. The USAF program to date has had as its general objective the development of reliable usable composite materials for airframes and engines. The present technology base is considered adequate for the design and fabrication of boron epoxy secondary structure and empennage structure consisting primarily of full depth sandwich construction. Composites use for local structural reinforcement has also been demonstrated as being practical. Engine applications have covered a relatively broad spectrum with boron/graphite/epoxy for cooler sections and metal matrices being investigated for hotter sections.

The Navy has concentrated its composites research programs for aerospace applications on graphite/epoxy with service applications of boron-epoxy.

The Army has examined helicopter blade, aft fuselage, and shafting applications of boron and graphite epoxy.

The service programs generally appeared to be complimentary and duplication of effort was not evident either in interservice or with NASA programs.

Present NASA Role and Program Plans

A comparison of future planned NASA programs with other agency programs was made by the Panel. Panel members felt that the NASA effort in aircraft applications is technically well oriented, but somewhat concentrated on Selective Reinforcement and too diffused on other types of composite approaches. Although most effort now underway will be helpful eventually, a specifically oriented program for civil application was minimal. This was true for other agencies as well. The present technology goals and levels of funding in NASA are inadequate to provide significant advances or National enthusiasm for the program.

In response to the Advisory Committee recommendation for NASA to conduct studies of composite application to civil aircraft, the Panel agreed that this should be a necessary prelude to definition of a specific future program. Dr. Brooks reviewed the Langley Research Center plan to respond to the recommendation. He stated that three steps are involved in the effort:

1. Formulation of an effective plan.

2. Development of an effective cost-weight analysis.

3. Transposition of these data to a merit value to the National economy.

Dr. Brooks felt that a combination of cost-weight-serviceability analyses will be required on a parallel effort basis. The formulation of an effective plan will require several iterations. A review by members of the Panel and the Committee was desirable prior to its issuance as a statement of work.

Examples of the type of study required was contained in two McDonnell-Douglas papers provided by Mr. Siegel of the Advisory Committee and Mr. Stone, a past Committee member. (References 1 and 2)

Additional points brought out in discussions were that system studies should provide justification, economic and other, for, and priority ordering of composites research relative to other technologies. The economics of successful applications of composites to achieve performance and other advantages over other approaches may well be favorable when interactions with other technologies such as aerodynamics, propulsion, and electronics are considered and the ultimate extents of operational advantages are identified. Therefore, the methodology employed in system studies must be sophisticated enough to expose the sensitivity of future designs to judicious composite applications. Effects should be identifiable such as improved performance, reduced maintenance costs, reduced initial investments, and increased structural reliability. Systems studies should develop time frame needs. The point was made that the advanced transport technology studies now underway may provide part of the data needed for larger aircraft.

Future NASA Program

The Panel recognized that some planning was already accomplished and included necessary and desirable goals. However, there was a question concerning long term and short term planning. Some members felt that only long term planning (10 years hence) and studies for applications in that period could be done. However, others felt that prototype application development programs were a near term desirable goal with more advanced material-structural developments as a far term goal. Discussion related to these categories contained the following points:

Near Term - It was suggested that NASA should immediately begin a hardware development program. Several objectives for such a program were discussed ranging from development of a prototype STOL aircraft airframe to components that would be interchangeable with aluminum on present civil transports and light airplanes.

In developing a prototype aircraft, thoughts were expressed that the design should reflect advantages of composites not only in reducing weight, but also in improving effectiveness of high lift systems, power plant performance, fatigue resistance, and increasing reliability. As a focal point for advanced composite technology development and application, the STOL V/STOL transport could be most effective and significant.

It was noted that airline operators had expressed a desire to evaluate composites through actual aircraft installation and use. Similar service testing was a possibility for general or light aircraft application. Therefore, it was suggested that NASA could provide a catalytic function in introducing high performance composites to both the airline and general aviation community by means of selected component development and test programs.

Long time service exposure data was considered to be one of the most serious obstacles in the way of composite acceptance in civil aircraft.

It was noted that long term properties for metals were not really known when metals were first applied and are still not known in many instances. However, if accelerated use of composites is to be encouraged, it would be highly desirable to try to devise accelerated service tests that will provide confidence and perhaps disclose potential problems and means for their correction. Such tests might include accelerated out-doors repeated load tests; accelerated ultra-violet and other high altitude radiation simulation tests; erosion tests; lightning resistance tests; and corrosion tests, for example. The desirability of starting simple tests now to acquire long time data concerning exposure to industrial, sea, and other borderline environments, including ordinary time, was also suggested. NASA especially should look at problems emphasized in commercial transport applications such as very long life, fail-safe design concepts, long time environmental protection and high utility.

There was considerable discussion of a possible NASA role of assisting in the development of realistic design criteria appropriate to aircraft employing composites. The possibility was cited that blind or arbitrary imposition of all-metal aircraft criteria to composite parts could be burdensome in some instances and could miss important points in others. As an example, criteria now applied by FAA to lightning protection requirements for metal aircraft do not reflect the different aspects presented by composites. The FAA itself is concerned about the lack of valid information on which to base new requirements. All-composite aircraft may be different from those which mix composite and metal structure. Subsequent to the meeting, a request was made by FAA letter that an Air Force finding relative to the immunity of all-fibreglass composite structure be confirmed by the Panel. While this phenomenon is important, it was pointed out that other conditions may be as serious, such as erosion, and should not be neglected in establishing a base for criteria.

It was suggested, therefore, that NASA might well devote effort to assisting FAA and other agencies in the development of realistic criteria for design involving environmental and phenomenalogical aspects in the proper balance.

<u>Far Term</u> - The role that NACA played in encouraging the development of sheet metal structures was discussed. Parallels were drawn to the need now for design support material such as allowables for materials and elements,

analytical methods, conceptual approaches for structural elements similar to those developed years ago for tension field beams, wing covers, cylinders, stress concentrations, joint analyses, etc. The suggestion was made and supported by several members that NASA might collect available data from military programs, supplement it in some instances, and publish it for use by civil oriented engineering organizations to the advantage especially of small (and large) companies who could not undertake such programs on their own.

There were no strong opinions expressed concerning differences in fibers or matrices, indicating at this stage of composite application development that no particular approach had outstanding attributes over others. The USAF recent emphasis on boron/epoxy applications and NASA emphasis to date on selective reinforcements using boron/epoxy were noted as two relatively state-of-the-art developments. Regarding propulsion systems, especially civil systems, the promise of composites in enhancing performance was emphasized, the indications being that composite technology offered both weight reduction and improved overall efficiencies. Resin matrix composites suitable for production application for temperature ranges up to 400° and up to 700° and metal matrices up to 1800° and above were stated to be highly desirable, and there was general concurrence to this effect. Exploitation of low cost fibers and manufacturing technology, including non-destructive evaluation, was strongly supported.

Military engine programs do not necessarily provide technology needed to support desirable civil propulsion system requirements. Large fan developments using composites were encouraged. Such developments must include long service tests.

The importance of economics in civil aircraft composite applications was emphasized, thus suggesting that low cost fibers and manufacturing technologies might be a major factor in future applications.

It was suggested that some factors against composite use were not wholly technical, but basically reluctance to depart from tradition, lack of a large base of knowledgeable designers/fabricators, and too much dependence on the nebulous aspects of cost effectiveness (in general - confidence). It was noted that competition (both foreign and domestic) may force composite application. There are no studies which have shown negative benefits from composite applications. Most show large positive benefits. The long range cost benefits must always be considered in preference to immediate cost savings.

There was discussion to the effect that NASA could be objective in its approach to composite applications and that as an unbiased and technically oriented organization could be and should be encouraged to be a focal point between industry and all the services and agencies.

Funding - Discussions of funding requirements for future possible programs were not definitive, but it was generally agreed that present and near term funding plans were certainly not too high compared to the return that could be expected. Several people expressed the opinion that system design studies would support fund expansions by a factor of two or more and that funding requirements could readily exceed such figures if extensive hardware development and manufacturing programs were to be undertaken. It was generally agreed that a viable NASA program would require the same order of support as that of the USAF.

The suggestion was made that funding for total composite programs; i.e. military plus NASA might be limited, therefore that it would be prudent to develop as part of Dr. Brooks' study the possibilities of joint agency (DOT-NASA-DOD) cooperation in funding. The NASA C-130 selective reinforcement program was cited here as an example of the USAF cooperating in making available C-130 aircraft for operational evaluation of boron reinforced wing center section structure. This program was also cited as being quite demanding of NASA funds since it would involve hardware.

Conclusions and Recommendations

The Panel discussion emphasized the need for civil non-space oriented aircraft applications for composites on the basis of the various program comparisons. Emphasis on military aircraft technology appears adequate. The review of these programs revealed that between NASA in-house and contract programs and military service programs there were no significant duplications or overlaps. Current and anticipated military roles and objectives, though complimentary, leave civil private and commercial propulsion and airframe fields without specific composite technology development support, thus suggesting the need for an aggressive NASA composite program if civil aircraft purposes are to be served.

There was general agreement that overall system performance improvements were needed to keep the United States competitive and that composites applications were most promising in this regard.

The Panel generally agreed that the broad objectives for a future NASA role in composites can be identified, including possible levels of funding.

The Panel concurred that the system studies currently underway as part of the advanced transport technology program and the more specific proposed study outlined by Dr. Brooks would lead to a definitive program for the future. The Panel recommended that these studies be pursued to identify major needed work areas and the rewards for successful R&D effort. The results should be additionally helpful in ordering priorities of composite research with those of other technologies.

The primary broad objective for a NASA program should be the development of technology to provide confidence required for acceptance of composites by industry. Such confidence will no doubt necessitate expanded hardware design development and flight service evaluation.

Regarding funding of future NASA programs, it was concluded that present funding levels are not adequate to cover future needs, especially if hardware development programs were entertained. The general feeling was that present funding would have to be increased by a factor of two, at least, and that NASA funding ought to be at roughly the $10 million level to produce a viable program. It is recommended that NASA system studies be completed and funding goals be set depending upon the total picture at that time.

The Panel generally agreed that NASA programs should emphasize hardware development for flying demonstrations on both light and heavy civil aircraft, including civil propulsion systems. A prototype airframe such as a STOL aircraft might be desirable for demonstration of overall benefits of composites. However, the Panel recognized that economics and other considerations might dictate a less complex test article, such as a significant portion of a STOL or other prototype vehicle.

Proposed Recommendations for Committee Action

On the basis of the foregoing discussions and conclusions, a resolution was proposed to be considered by the Materials and Structures Advisory Committee as follows:

Whereas: A review of the current and planned NASA composite materials programs reveals that major emphasis is now placed upon the development of technology for military aircraft applications and essentially no program exists for a civil oriented composites technology development and,

Whereas: NASA is in a unique position as an unbiased technically oriented agency and could be a focal point between industry and other agencies and,

Whereas: A precedent has been established by earlier NACA research in metal structures,

Therefore, be it resolved that the following objectives be incorporated in the future NASA program for composite materials technology development for application to aircraft structures:

Near Term

1. As previously recommended by the Materials and Structures Advisory Committee, near term cost benefit studies and design optimization studies should be completed by NASA, on contract, on the use of composites in civil aircraft. Those studies are expected to be of material assistance in defining in total the economic benefits of composite applications and specific future R&D composites roles and activity levels.

2. Initiate a program which will develop empirical and theoretical analytical design methodology and data including:

a. Coordination with DOD organizations to utilize information available from military programs and to identify areas requiring further development, particularly for civil applications.

b. Coordination with DOT (FAA) prior to publication of reports incorporating design methodology such that proper emphasis will be given to development of realistic criteria.

c. Implementation by publication of technical reports, notes, and by holding various symposia to establish a focal point for both industry and government civil composite technology development.

3. Exploit current STOL/VSTOL and ATT studies to determine the practicability of incorporation of composite structural components, panels, etc. for the purpose of establishing actual use data and development of confidence.

4. Initiate, by means of discussions with industry, airlines, and other agencies, a plan to explore the practicability for incorporation of both primary and secondary structural components, panels, etc. in civil aircraft.

5. Implement these studies and plans by means of hardware programs. These could include incorporation of composites in research prototype aircraft, and include using limited production runs to incorporate composite primary and secondary structure on civil aircraft.

6. Develop technology for incorporating composites in civil aircraft engine propulsion systems, particularly regarding improved materials for environmental resistance, foreign object damage tolerance, and long life, in fans and compressor blades, discs, and casings.

Far Term

1. Continue with and implement research to develop higher temperature composite matrix materials for incorporation in civil aircraft propulsion systems, including turbine blades.

2. Develop conceptual design approaches which will result in novel and improved methods of composite design and overall aircraft configurations.

3. By further coordination with the DOD identify and implement technology needed for improved future military applications.

Funding

NASA should increase present funding levels by at least a factor of 2. A level of effort of approximately $10 million per year is considered required for a viable program. Cooperative programs with other agencies will increase the productivity of this level of funding.

REFERENCES

1. Augustus, J. E. - "The Influence of Composite Materials on Aircraft Weight, Design, and Performance", 30th Annual Conference of the Society of Aeronautical Weight Engineers, Newport Beach, California, May 3-6, 1971

2. Schjelderup, H.C. and Purdy, D.M. - "Advanced Composites - The Aircraft Materials of the Future", AIAA Third Aircraft Design and Operations Meeting, Seattle, Washington, July 12-14, 1971

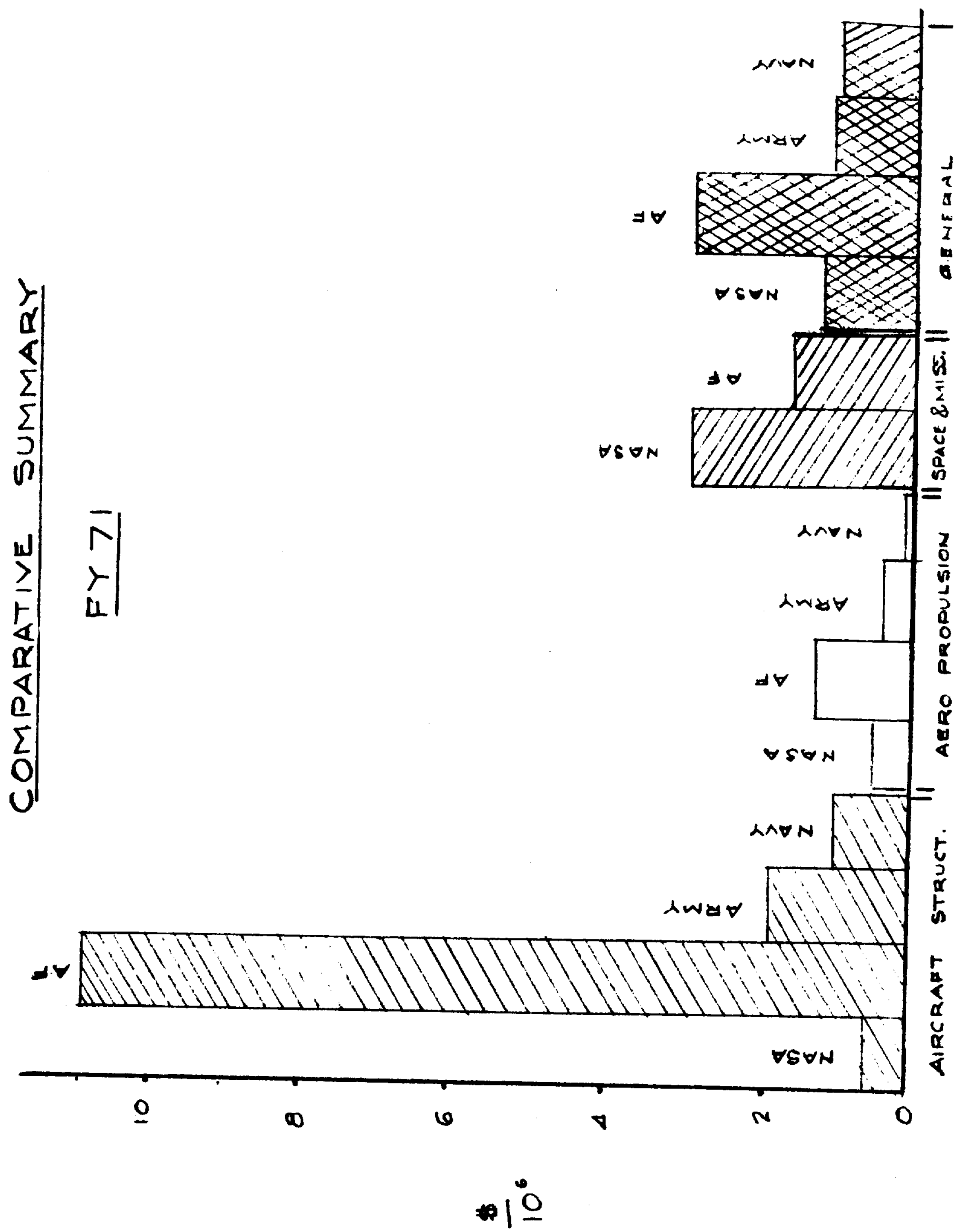
COMPARATIVE SUMMARY
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FIGURE 1

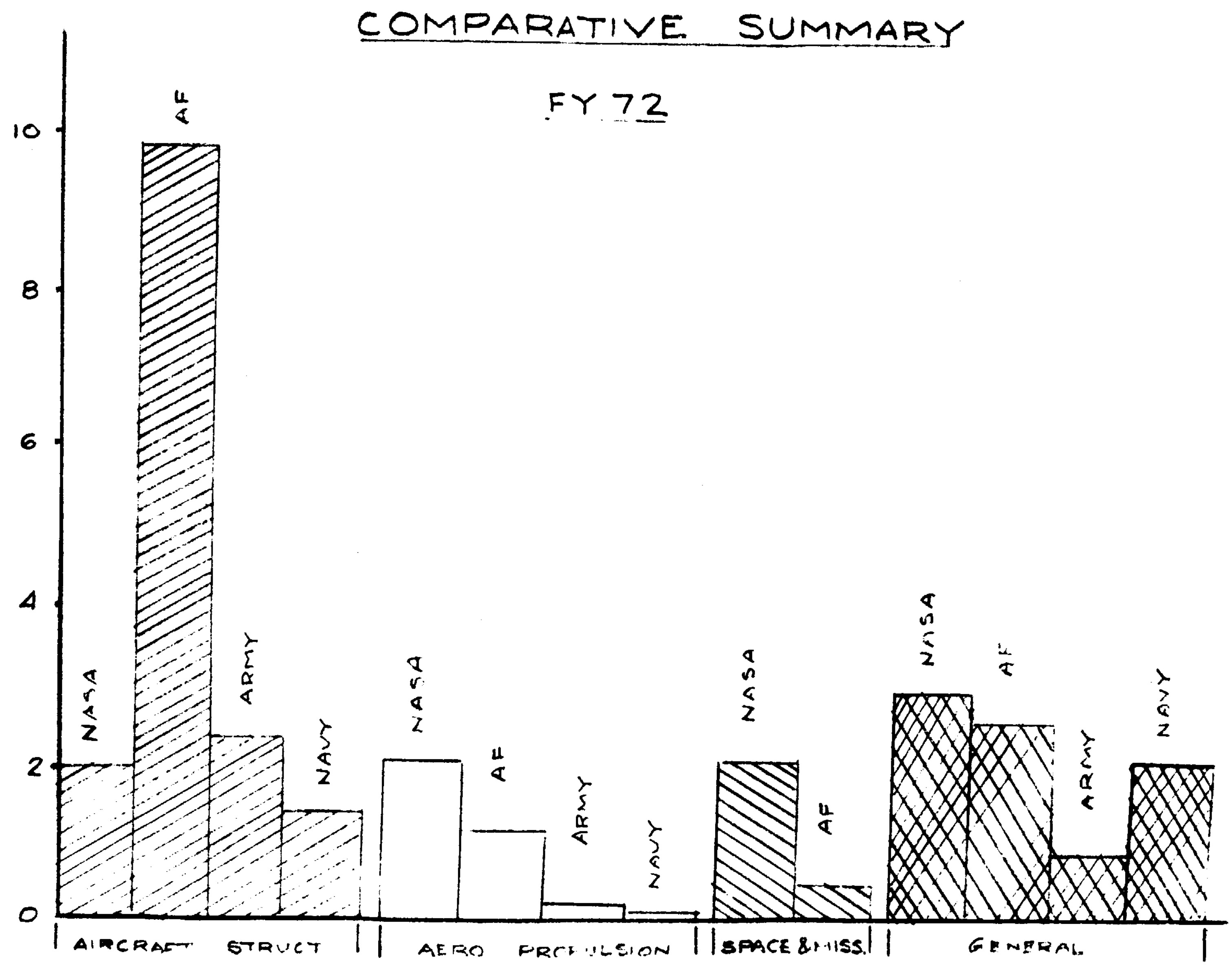
COMPARATIVE SUMMARY
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FIGURE 2

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COMPARATIVE SUMMARY

FY 73

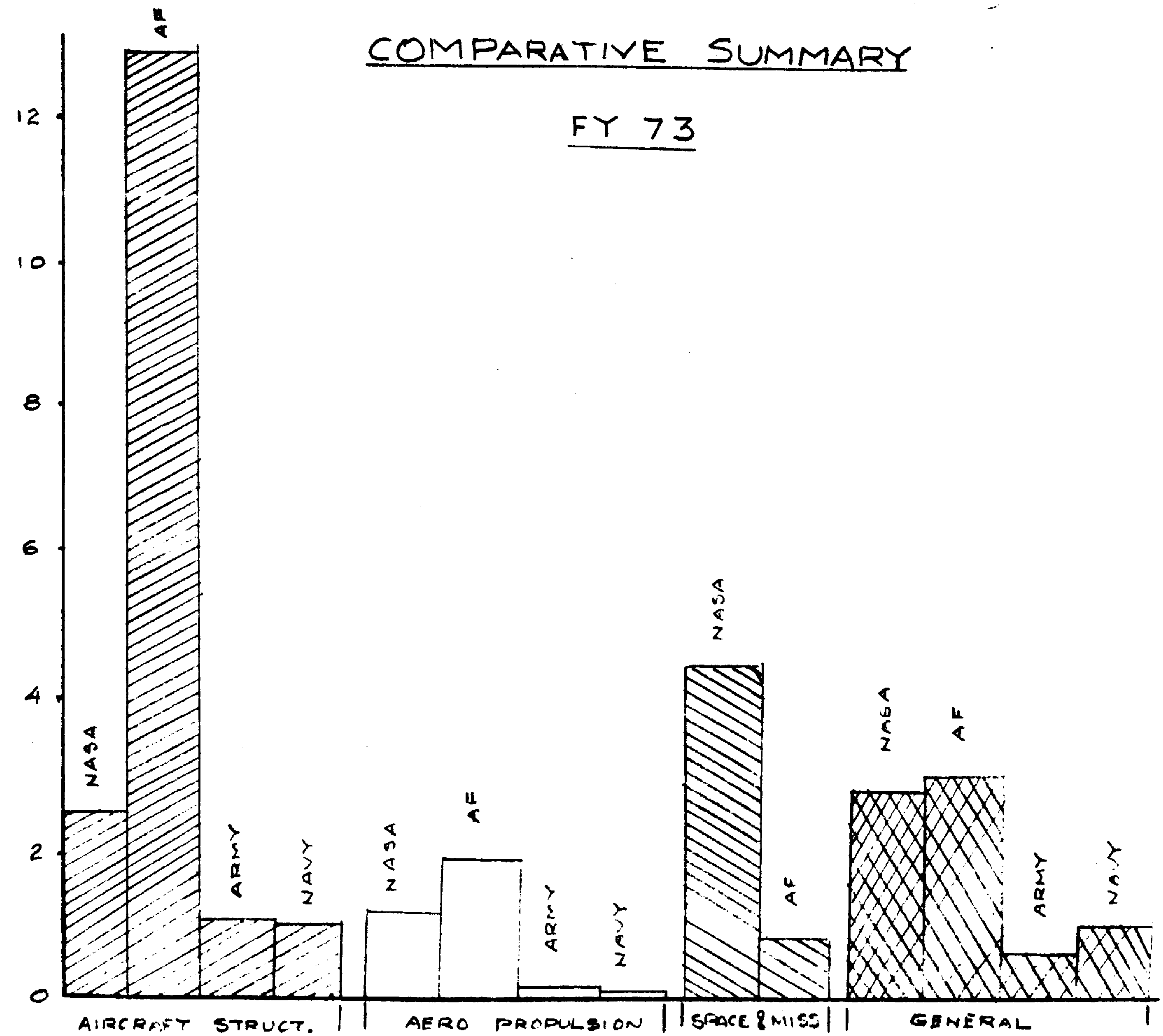

FIGURE 3